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Technical Lesson 7

RESISTANCE AND CONDUCTION

Resistance is a term known to all of us and it means opposition or an opposing force. This force of opposition can be in two forms; it may be stationary or in motion.

No matter what work is done resistance is present in some form or other. When you walk resistance tends to retard your action; when you row a boat the water offers resistance to the forward motion of the boat. Water running through a pipe is retarded by friction caused by the water making contact with the sides of the pipe. It is readily seen then that resistance is something that must be overcome. If a pipe is clean water will flow through with comparative ease; if we allow rust and silt to collect in the same pipe it will require more pressure to force the water through, hence the rust and silt is an obstruction or resistance to the flow of water and a greater pressure is required to overcome this resistance offered to the passage of water.

In an electrical circuit resistance is also present and, before current can flow, the resistance must be overcome in the circuit by a pressure or force. An electromotive force of sufficient pressure must be applied to the circuit to force the current through the conductor thus overcoming its resistance.

No electrical circuit can be devised without some resistance but certain circuits may offer less resistance to a current of electricity than others, depending upon the conductors used. If the resistance is low the conduction is good, or, as we say when speaking of certain wire, it is a good conductor of electricity. Conversely, if the resistance of a material is high we have poor conduction; in other words, the material is a poor conductor. Certain materials offer such a very high resistance to the passage of electric current that there is practically no conduction; such materials are called non-conductors or insulators.

In materials capable of carrying electric current the molecular structure is such that the electrons, a part of matter, can be forced into motion thereby producing a flow of electric current.

Materials classed as insulators are substances, the molecular structure of which is so arranged that electrons cannot make any appreciable movement, because they are tightly held within the atom of which the insulator is composed.

With these two classes of materials we can make up a circuit of materials the nature of which will either obstruct or allow current to flow.

To force electrons to move from one part of an electrical circuit to another resistance must be overcome and force must be applied. This force is called electromotive force and abbreviated E.M.F.

When an E.M.F. has been applied to a conductor a current is found to flow through the conductor, providing the conductor forms a complete path. The unit of current is called ampere. (Note. Bear in mind the circuit must be complete. A great E.M.F. may be applied to a conductor but unless the circuit is continuous no electrons move, hence no current flows.)

E.M.F. then, is the electrical force necessary to move electrons in a conductor against the resisting forces of the atom which tend to prevent the electrons from moving from one atom to another.

The material, its size, and its physical state, such as its temperature, etc., determines just how much it will oppose the free movement of electrons, or, in other words, its resistance.

The Ohm is the unit of resistance, shown in symbol as Ω , and denotes the opposition offered to an electron movement (electric current) through a substance.

Conductance is the opposite of resistance and we can find the terms for it if we spell OHM backwards, giving us MHO. Mho then is the unit of conductance or the measure by which we indicate the ease which the electrons can be moved through a substance.

Any electrical conductor has both resistance and conductance and, in electrical practice, we select for our purpose material which offers small resistance to the flow of current when we desire high conductance. If low conductance is desired we use another class of material which has a high resistance and which obstructs or opposes the flow of current.

Resistance in any electrical circuit offers a wide range of study and the purpose of this lesson is to point out to the student the various forms of resistance which may be encountered in radio practice, and the terms used to classify such resistance.

Ohmic resistance of direct current circuits may be determined by the application of Ohm's Law when the current and voltage values are known. Resistances necessary to control current and voltage values of vacuum tube circuits may be classified under the following names,-- Resistor, Rheostat and Potentiometer.

Different materials are used in making these various units of resistance, such as carbon or the combinations of different metals which, when combined, are termed alloys.

By winding german silver or climax resistance wire on a suitable support, such as porcelain or a non-inflammable composition form, a unit to act as an opposition to the flow of electric current may be had. Such a form is suggested in Figure 1 and constitutes fixed resistance.

Resistors are found in various forms and sizes and are made to meet most any condition. Figures 2 and 3 show types of Resistors used in Radio receivers.

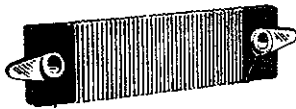


Figure 1

"Rheostat " is a term applied to a form of resistance which is adjustable. By the use of a rheostat current flow can be controlled at the will of the operator by simple adjustment of the rheostat. This form of resistance is shown in Figure 4.

The Potentiometer is another form of resistance employed to perform a certain function in controlling the action of certain parts of radio circuits. It usually consists of resistance wire wound into units having a value of from 200 to 1,000 ohms. The use of the potentiometer is to divide potentials between parts of a single circuit or to divide a potential difference between two or more circuits. Explicit instruction concerning the use of these units will be given when we get to that point in our studies wherein we employ these devices.

INDUCTIVE REACTANCE

Current flow in alternating current circuits is affected by inductance which is a form of resistance termed inductive reactance, and which is measured in ohms.



Figure 2

CAPACITIVE REACTANCE

Capacity also constitutes a form of resistance and is called capacitive reactance, also measured in ohms.

IMPEDANCE

The combination of inductive reactance and capacity reactance and pure ohmic resistance offers opposition to current flow in alternating current circuits. This total opposition is termed impedance. Impedance is also measured in ohms and is designated by the symbol " Z " which displaces " R " in the Ohm's Law formula. Further discussion on this subject is presented under "Inductance and Capacity".



Figure 3

It is clearly seen that resistance is a factor which must be taken into account in all electrical circuits. All substances are found to resist the passage of electricity but the resistance of metals is less than all other substances, that of course being the reason for the adoption of metals to serve as carrying agents of electricity.

CONDUCTORS

The best conductor of electricity is silver because it offers the least resistance or opposition to current flow and is taken as the basis of comparison in computing the resistance of other metals. The specific resistance of any material is the resistance of a unit length of that material and the unit cross sectional area at a pre-determined degree of temperature. It is in reality the resistance of any substance one cubic inch square when measured at a temperature of melting ice (32°F). The table shows the relative resistance of chemically pure metals at the temperature of 32° Fahrenheit.

METAL	RELATIVE RESISTANCE	RESISTANCE IN MICROHMS PER CUBIC INCH
Annealed silver	1.000	0.5904
Annealed copper	1.063	0.6274
Hard drawn silver	1.086	0.6415
Hard drawn copper	1.086	0.6415
Annealed gold	1.369	0.8079
Annealed aluminum	1.935	1.144
Pressed zinc	3.741	2.209
Platinum	6.022	3.555
Annealed iron	6.460	3.814
Lead	13.05	7.706
German silver	13.92	8.217

By studying the table it is seen that German silver has a specific resistance very nearly 14 times as great as annealed silver. German silver not only has a high resistance but the resistance so offered is more or less constant, that is, it does not fluctuate in resistance value with changes of current strength to as great an extent as other metals.

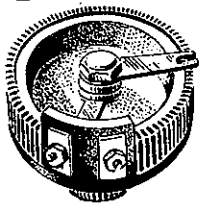


Figure 4

It has been found by experiment that the total resistance of a conductor varies directly as the specific resistance and length, and inversely as the cross sectional area. These quantities are related as shown by the following formula:
 "Resistance equals the material times the length of the conductor divided by its cross sectional area."

When we know the cross sectional area and the length of a conductor the specific resistance of the wire may be obtained from the table just given and, by substituting the values in the above formula, the resistance can easily be found.

Temperature changes will affect the resistance of an electrical conductor and, in general, the resistance of metals increase as the

temperature increases. For example, the mixture of chemicals and water used in storage batteries will decrease in resistance as the temperature of the solution rises. Carbon filaments, such as used in the early types of electric lamps, have but half as much resistance when white hot as when cold. The resistance of a conductor, however, will remain constant in value as long as the temperature remains constant.

To grasp the idea of one ohm resistance examples of conductors having approximately that value of resistance are given. For example, two hundred and fifty feet of number sixteen "Brown and Sharp" gauge copper wire having a diameter of one twentieth of an inch has a resistance of one ohm. One thousand feet of number thirty-two "B & S" bare copper wire has a resistance of one hundred and seventy and seven tenths ohms. From this it is seen that a large gauge copper wire has a resistance value less than one of smaller gauge.

INSULATORS

Other substances may be selected which have higher resisting powers than metals. We may continue to select materials until we arrive at the point where it becomes very hard to force electric current through the substance so selected. Such substances are termed Insulators and they have extremely high resistance. Any material may be classed as an insulator which will not allow electric current to flow, that is, which will prevent the passage of electric current through the mass of the substances.

It is well to state at this point that there is no perfect insulator any more than there is a perfect conductor. If a potential of sufficient strength is impressed across an insulator the insulating properties will break down and a flow of current takes place, this flow of current often being termed "leakage".

The insulators shown in Figure 5 are familiar types and are generally made of material which offer great opposition to current flow. The corrugations or irregularities in the surface are purposely placed there to increase the surface area of the insulator. A film of moisture sometimes collects on insulators and this film is more or less a conductor of electricity. The corrugations or irregular surface aids in reducing what is termed "surface leakage".

Other forms of insulators shown in Figure 6 are known as porcelain cleats. Figure 6A shows a cleat in place, holding two wires, and nailed or screwed to a joist or timber. The insulators shown in Figures 7 and 7A are porcelain tubes and are used for passing electrical conductors through walls and partitions.

Figure 8 indicates the manner of connecting insulators to the two supported ends of the antenna used for broadcast receiving work.

Figure 9 is a form of insulator found on ship-board to insulate the antenna lead-in from the deck of the Radio cabin. This type of insulator must withstand the strain of 30,000 volts and, in some installations, even greater values of potential. This type is known as the electrose moulded insulator. A heavy brass rod is moulded securely into it which terminates at either end in a connection lug. The outside of the insulator is threaded as shown at "A". A five inch hole is cut in the Radio cabin and the upper half of the insulator "B",

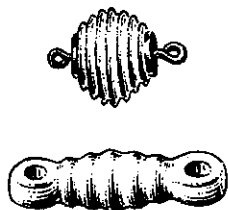


Figure 5

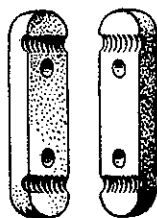


Figure 6

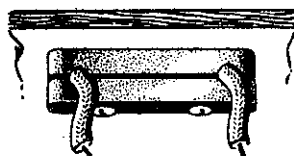


Figure 6A

carrying the threaded portion "A", is dropped through the hole and that part of the insulator marked "C" rests on rubber washers which insulates it from the deck. The lower half which is threaded inside at "D" is then screwed onto the threaded part "A" and drawn up tightly with a wrench.

Another form of insulator, called the Bradfield type, is shown in Figure 10. A long hard rubber tube "T", about two inches in diameter, has a brass lug, "L". The tube is threaded at the center to take two wooden blocks B1 and B2, one being placed above the deck and the other below. Washers are used between the deck and each block. The blocks are then drawn up tightly by means of screws. The cone shaped metallic hood "H" serves to protect the rod from dampness.

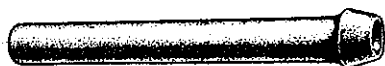


Figure 7

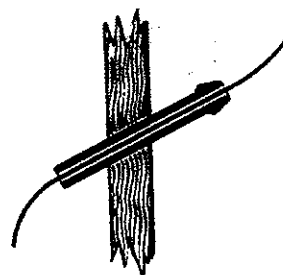


Figure 7A

Other insulating materials used in radio circuits are given below in order of their increasing resistive value: Dry air, paraffine, resin, sulphur, wax, glass, mica, India rubber, silk, paper and oils. These resisting elements in the radio circuit are commonly used as insulation around coils or as dielectric mediums. The resistance of such materials is measured in ohms and is called the insulation resistance. It is computed from the voltage applied under exacting conditions when temperature, exact size of material, humidity, etc., are taken into account during the measurements.

The air between the plates of variable condensers is an insulator and if you will examine a fixed condenser, you will often find either

paraffined paper, mica, or perhaps oiled silk, used as the dielectric medium. These materials all act as such because of their extremely high resistance.

When computing the resistance of antennae all losses must be considered. They are, first, the Ohmic resistance of the wires of the antenna circuit; second, leakage over the surfaces of insulators and, third the absorption losses when the antenna is in the proximity of buildings, masts, trees, and other similar objects.

When high frequency currents are used, as in radio work, the resistance is the total of all oppositions and losses due to the nature of the current. The Ohmic resistance of all wires of the circuit must be considered as well as capacity, inductive and eddy current losses, all of which increase the resistance.

Resistance, therefore, is to be found in many forms through the electrical circuit. In some places it is useful while in other parts of the circuit it is detrimental and wholly undesirable.

In calculating the resistance of conductors the mil-foot is the unit

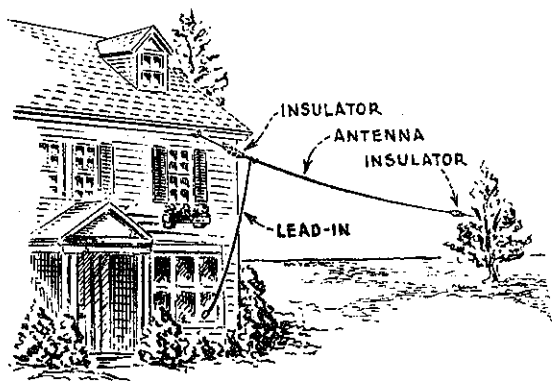


Figure 8

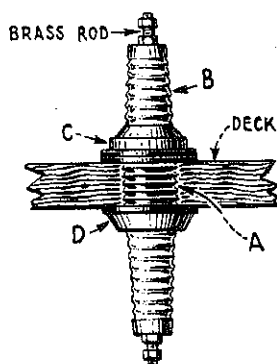


Figure 9

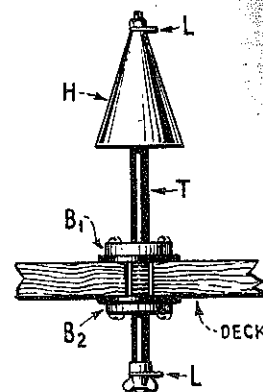


Figure 10

employed. A wire one foot in length and one mil in diameter is a mil-foot and if this wire has a resistance of two ohms, it is said to have a resistance of two ohms per mil-foot. In electrical parlance, mil means one one-thousandth of an inch. It is invariably used to specify the diameter and cross-sectional area of such conductors as wires, cables, etc. For example, if a wire is said to have a diameter of three mils, then it has a diameter of 0.003 inch. Squaring the diameter of a wire in mils gives its cross-sectional area in mils; more specifically called its "circular mil area".

The resistance of any wire varies in a direct proportion to its length and in inverse proportion to its cross-sectional area. The following formula may be used to determine the resistance of any wire of circular form: Resistance =

$$\frac{\text{Resistance per mil-foot} \times \text{length in feet}}{D \text{ squared}}$$

This formula may be written as follows: $R = \frac{ML}{D^2}$, where M is a constant dependent upon the material used, D^2 equals the cross sectional area in circular mils and L is the length of the conductor in part. When the resistance of copper wire is being computed M equals 10.4 ohms, so if you were solving for the resistance of copper wire the formula would read,

$$\frac{10.4 \times L}{D^2}$$

In the following wire table helpful information is compiled for use in resistance calculation. From this table values may be obtained for substitution in the above formula for resistance of copper wire.

WIRE TABLE
B & S GAUGE

Gauge No. B. & S.	At 20° C.		Area		Ohms per 1000 ft. at 77° F. or 25° C.	Pounds per 1000 ft.	Max. Dia. S. C. C. in mils.	Turns per Linear inch S. C. C.	Max. Dia. D. C. C. in mils.	Turns per Linear inch D. C. C.	Dia. in Mils S. S. C. (G.E.Co.)	Dia. in mils D. S. C. (G. E. Co.)	Turns per S. S. C. (G. E. Co.)	Turns per inch (G. E. Co.)	Approx. Turns per inch Enameled
	Dia. in mils	Dia. in inches	Cir. mils	Square inches											
6	162	.1620	26250	.02062	4.028	79.46	172	5.60	189.	5.44					
7	144.3	.1443	20820	.01635	5.080	63.02	154.3	6.23	173.30	6.08					
8	128.5	.1285	16510	.01297	6.405	49.98	137.5	6.94	142.5	6.80					
9	114.4	.1144	13090	.01028	8.077	39.63	122.4	7.68	127.4	7.64					
10	101.9	.1019	10380	.008155	1.018	31.43	117.9	8.55	112.9	8.51					
11	90.74	.0974	8234	.006467	1.284	24.92	96.74	9.60	101.7	9.58					
12	80.81	.08081	6530	.005129	1.619	19.77	86.81	10.80	91.8	10.62					
13	71.96	.07196	5178	.004067	2.042	15.68	77.96	12.06	83.0	11.88					
14	64.08	.06408	4107	.003225	2.575	12.43	70.08	13.45	75.1	13.10					14
15	57.07	.05707	3257	.002558	3.247	9.858	63.07	14.90	68.1	14.68					16
16	50.82	.05082	2583	.002028	4.094	7.818	56.82	16.60	60.8	16.35					18
17	45.26	.04526	2048	.001609	5.163	6.200	51.26	18.20	55.3	18.08					21
18	40.30	.0403	1624	.001276	6.510	4.917	46.30	20.20	50.3	19.90					23
19	35.89	.03589	1288	.001012	8.210	3.899	41.89	22.60	45.9	21.83					27
20	31.96	.03196	1022	.0008023	10.35	3.092	37.96	25.30	42.0	23.91					29
21	28.46	.02846	810.1	.0006363	13.05	2.452	34.46	28.60	38.5	26.20					32
22	25.35	.02535	642.4	.0005046	16.46	1.945	31.35	31.00	33.3	28.58					36
23	22.57	.02257	509.5	.0004002	20.76	1.542	28.57	34.30	30.60	31.12	26.00	29.00	38	34	40
24	20.10	.02010	404.0	.0003173	26.17	1.2223	26.10	37.70	28.10	33.60	23.00	26.00	43	38	45
25	17.90	.01790	320.4	.0002517	33.00	.9699	23.90	41.50	25.90	36.20	21.00	24.00	47	41	50
26	15.94	.01594	254.1	.0001996	41.62	.7692	21.94	45.30	23.04	39.90	19.00	22.00	52	45	57
27	14.20	.01420	201.5	.0001583	52.48	.6100	20.20	49.40	22.20	42.60	17.00	20.00	58	50	64
28	12.64	.01264	159.8	.0001255	66.17	.4837	18.64	54.00	20.64	45.50	15.60	18.60	64	53	71
29	11.26	.01126	126.7	.00009953	83.44	.3836	17.26	58.80	19.36	48.00	14.00	17.00	71	58	81
30	10.03	.01003	100.5	.00007894	105.20	.3042	16.03	64.40	18.03	51.10	12.50	15.00	80	66	88
31	8.928	.00892	79.70	.00006260	132.70	.2413	14.93	69.00	16.93	56.80	11.4	13.90	87	71	104
32	7.950	.00795	63.21	.00004964	167.30	.1913	13.93	75.00	15.95	60.20	10.50	13.00	95	76	120
33	7.080	.00708	50.13	.00003937	211.00	.1517	13.08	81.00	15.08	64.30	9.50	12.00	105	83	130
34	6.303	.006303	39.75	.00003122	266.00	.1203	12.31	87.60	14.31	68.60	8.80	11.30	110	88	140
35	5.615	.005615	31.52	.00002476	335.50	.09542	11.62	94.20	13.61	73.00	7.60	9.6	130	104	160
36	5.000	.005	25.00	.00001964	423.00	.07568	11.00	101.00	13.	78.50	7.00	9.00	140	110	190
37	4.453	.004453	19.83	.00001557	533.40	.06001	10.45	108.00	12.45	84.00					
38	3.965	.003965	15.72	.00001235	672.60	.04759	9.965	115.00	11.96	89.10	6.00	8.00	160	120	
39	3.531	.003531	12.47	.000009793	848.10	.03774	9.531	122.50	11.53	95.00					
40	3.145	.00314	9.888	.000007766	1069.00	.02993	9.145	130.00	11.15	102.50	5.00	7.00	200	140	230

CONDUCTANCE

Conductance, as stated before, is the ease with which electric current is forced through the circuit.

Conductance is most easily remembered as being exactly the opposite of resistance. For example, suppose three rheostates have a resistance of 20 ohms, 10 ohms and 5 ohms respectively; the conductance would be $1/20$ mho, $1/10$ and $1/5$ mho.

At times, in calculating the resistance of a parallel circuit, it is expressed in terms of conductance as follows: "To find the resistance in terms of conductance add the conductance of the several branches to obtain the total conductance of the combination; this result inverted gives the resistance."

EXAMINATION - LESSON 7

1. Is there a perfect insulator or a perfect conductor?
2. For all practical purposes what substances make the best conductors?
3. Does air offer resistance?
4. Give a clear definition of "impedance".
5. Just why are insulators used? What would happen to the received radio signals if the insulators shown on the aerial in Figure 8 were removed?
6. Is it possible for electrical circuits to have no resistance?
7. What does the term "alloy" mean?
8. Why is it that some resistances, or resistors, offer more resistance than others?
9. What is the total conductance of a circuit in which three resistors of 5 ohms 10 ohms and 20 ohms are connected in parallel?
10. What material, in your estimation, offers the greatest amount of resistance to the flow of current?